



Recent Results from EXO-200

Tim Daniels
UMass Amherst
on behalf of the EXO Collaboration
TAUP 2013
9/10/13

EXO: Searching for double beta decay using an enriched Xe time-projection chamber (TPC)

Why Xe?

Xenon isotopic enrichment is easier. Xe is already a gas & Xe^{136} is the heaviest isotope.

Xenon is “reusable”. Can be repurified & recycled into new detector (no crystal growth).

Monolithic detector. LXe is self shielding, surface contamination minimized.

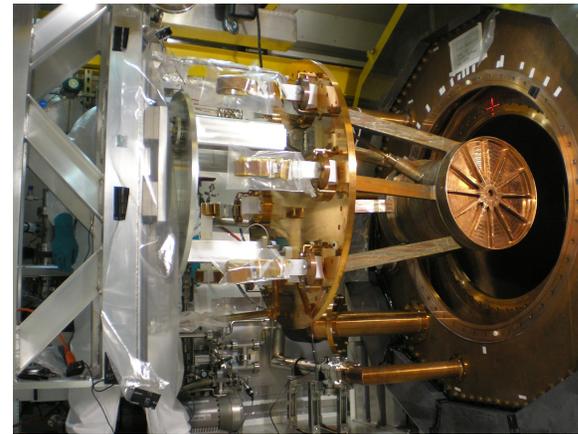
Minimal cosmogenic activation. No long lived radioactive isotopes of Xe.

Energy resolution in LXe can be improved. Scintillation light/ionization correlation.

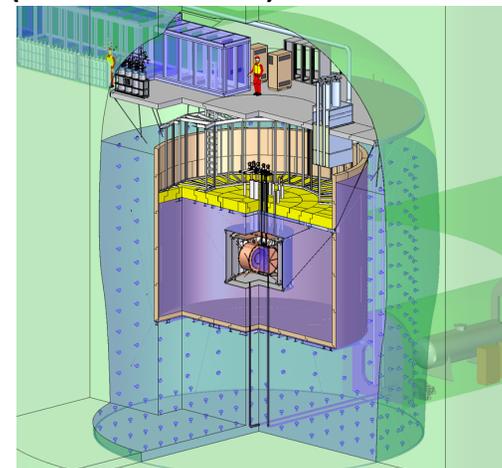
... admits a novel coincidence technique. Background reduction by Ba daughter tagging.

Phased approach:

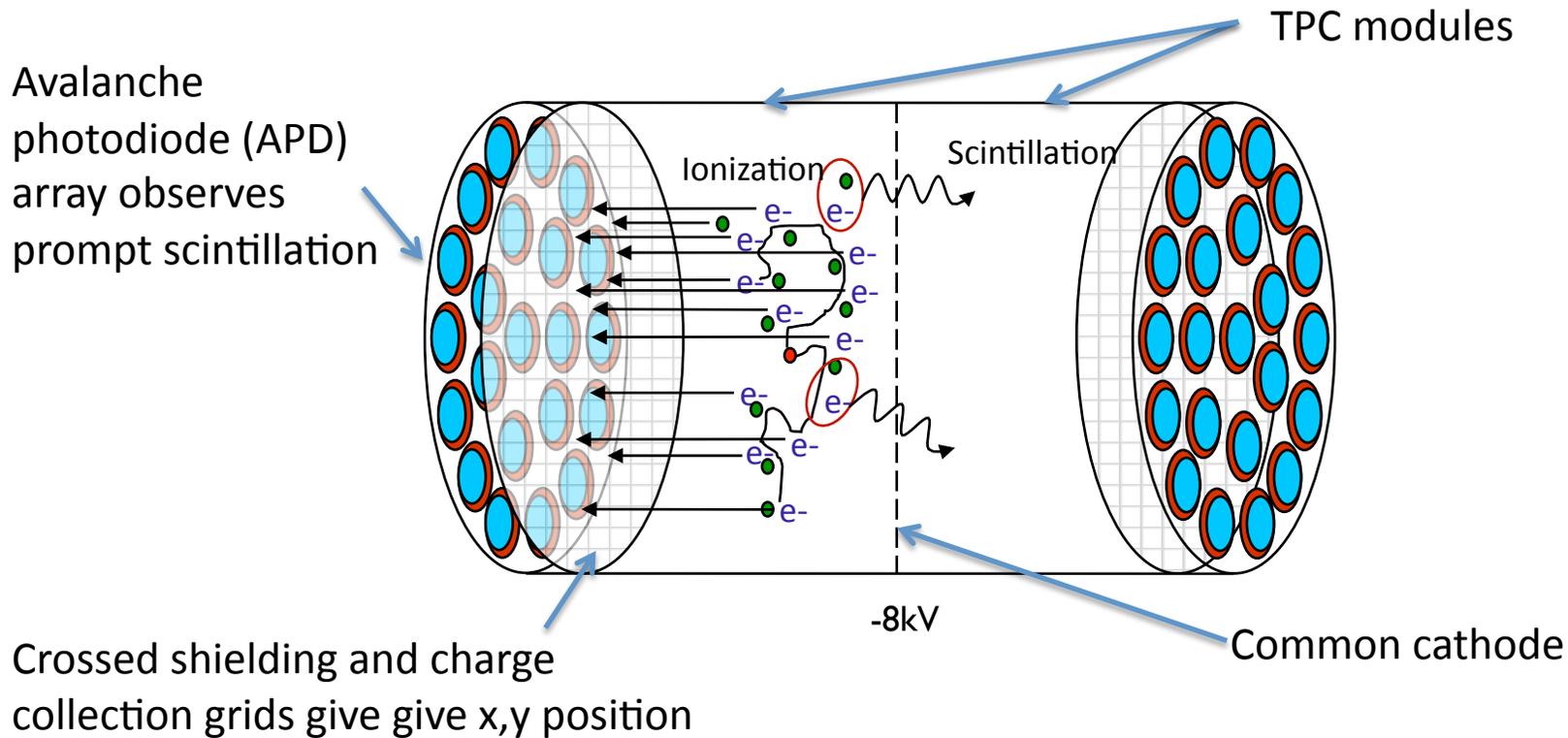
1. EXO-200: 200kg liquid-xe TPC (this talk)



2. nEXO: 5-ton liquid Xe TPC with Ba tagging option (see next talk)

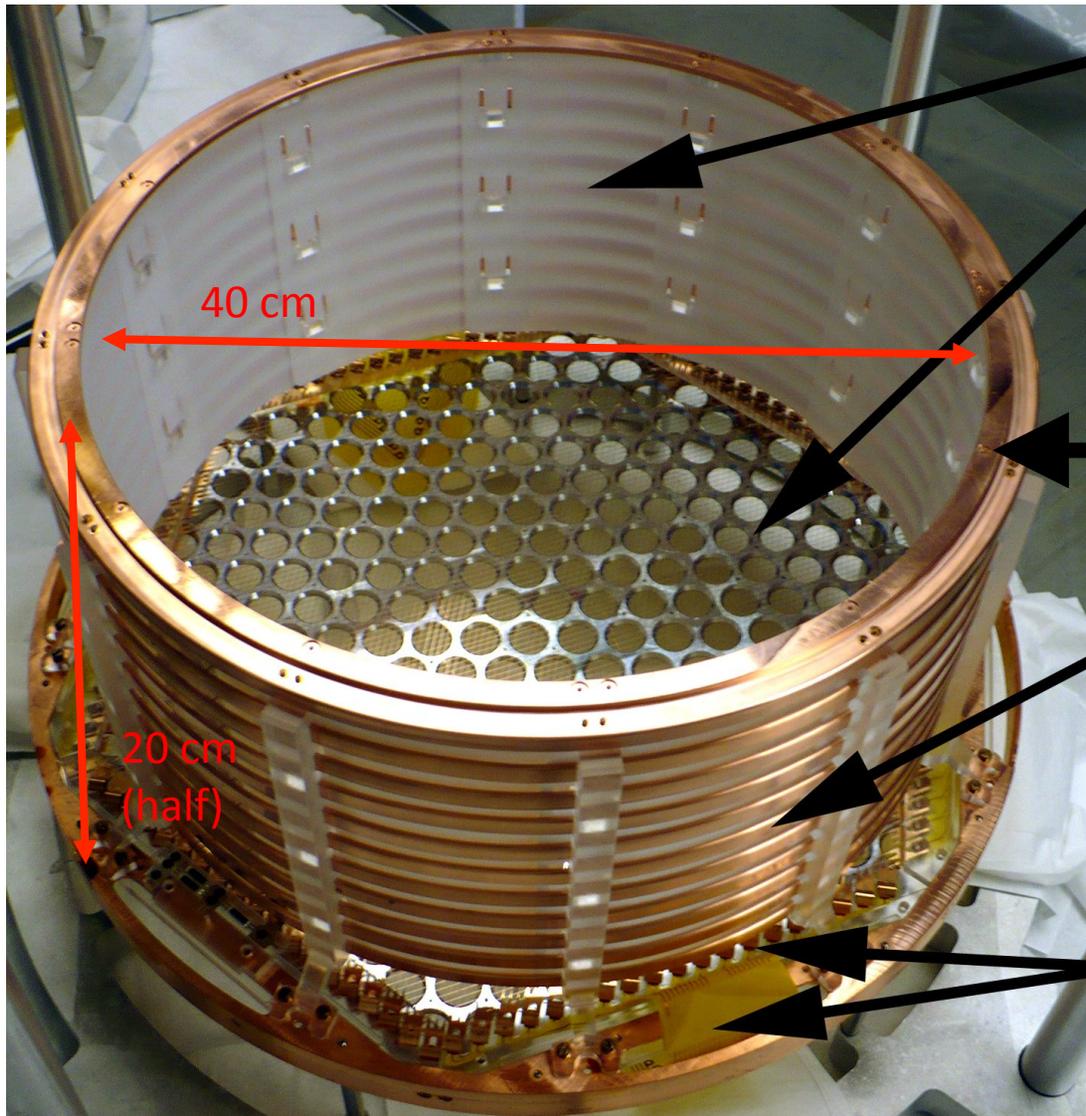


EXO-200 Time Projection Chamber (TPC) Basics



- Z-position from the time difference between scintillation and ionization
- Event energy from the combination of ionization and scintillation
- TPC allows rejection of some gamma backgrounds because Compton scattering results in multiple energy deposits

EXO-200 TPC



Teflon Reflectors
(increase light collection)

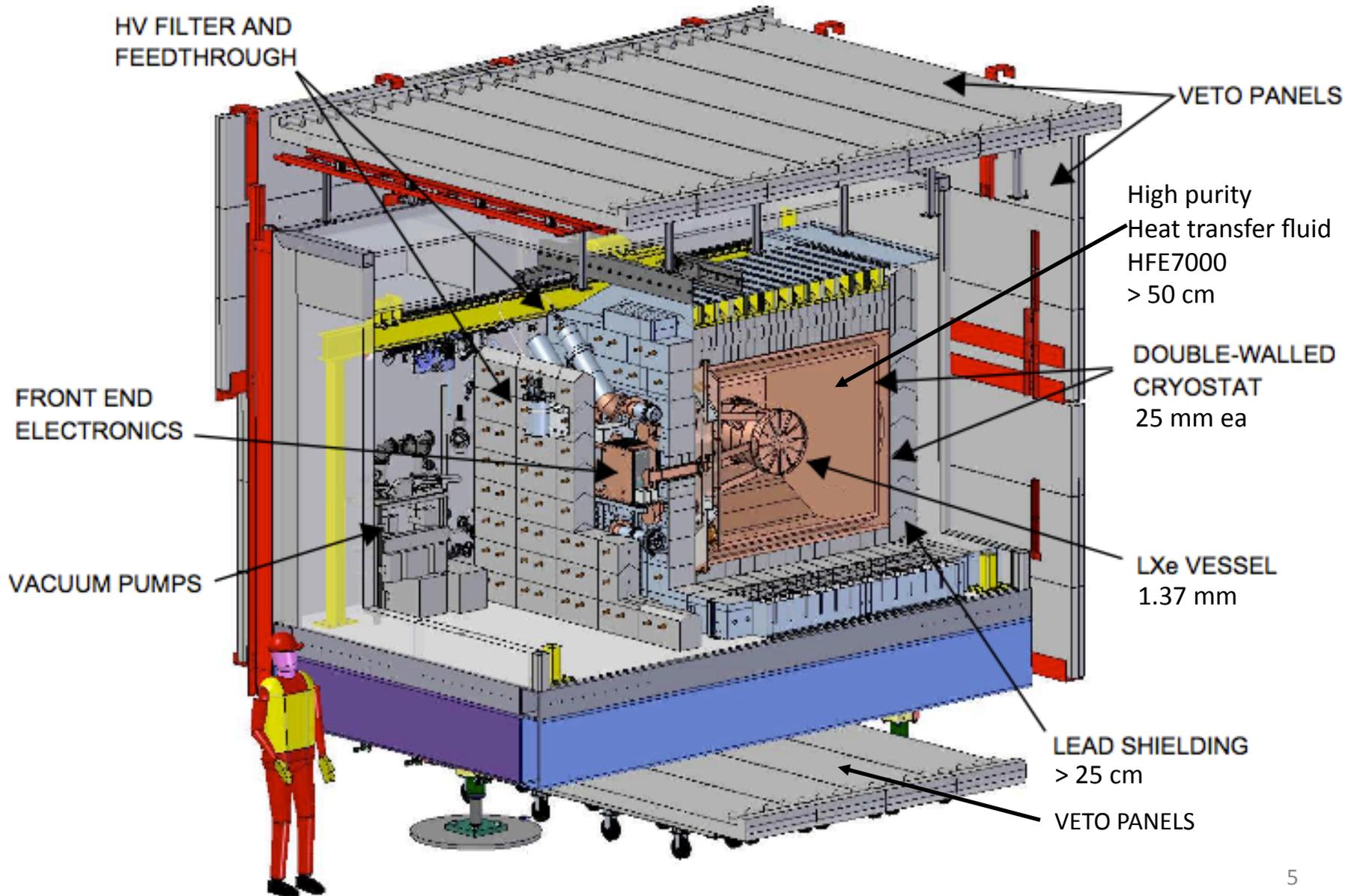
APD plane and wire planes
(wires are photo-etched)

Central HV plane
(photo-etched phosphor bronze)

Acrylic supports
and field shaping
rings

Kapton flex cables
(spring connections
eliminate solder joints
and glue)

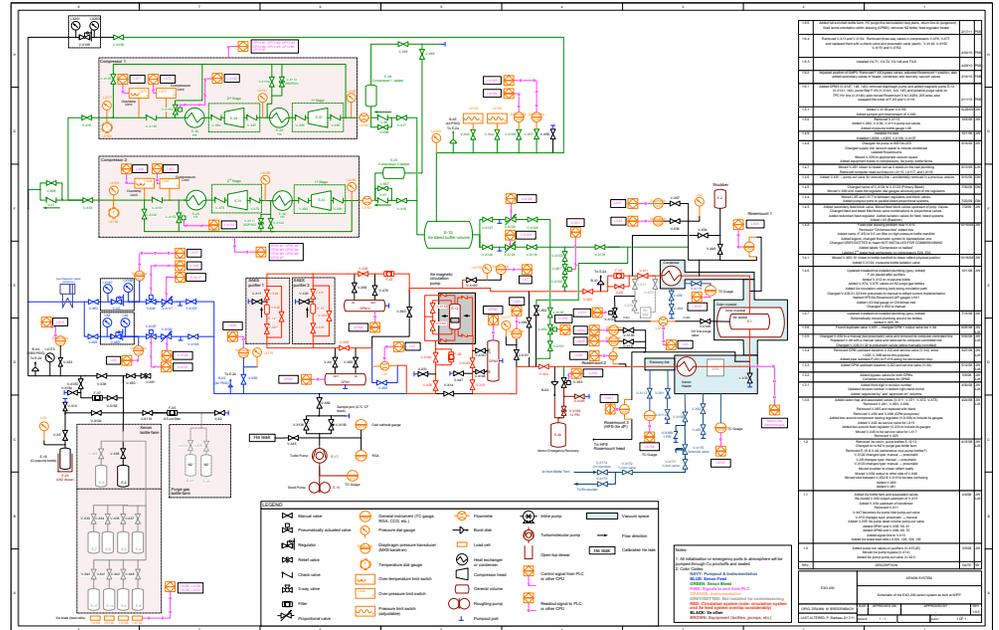
The EXO-200 Detector



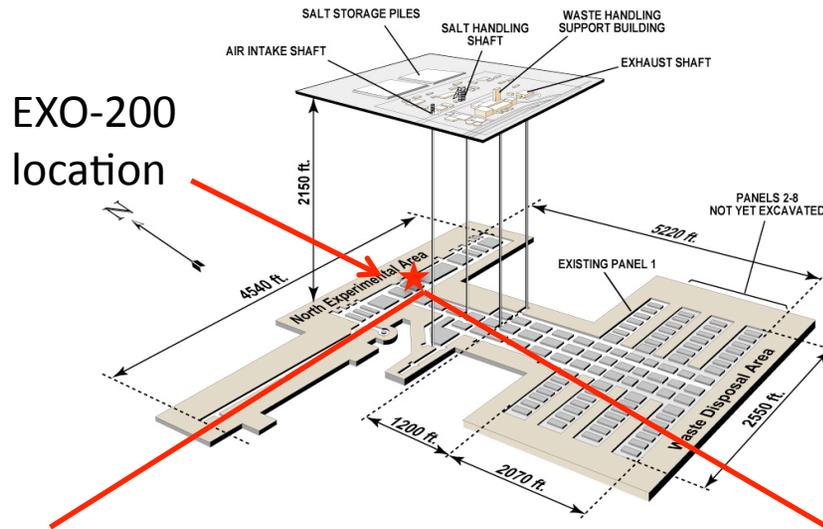
Subsystems

Substantial system required to:

- Protect the thin-walled Xe chamber from differential pressure (“dp”)
- Boil, purify, and recondense Xe
- Fill and empty the detector
- Manage emergencies
- Cool the cryostat
- Battery backup
- And more!



EXO-200 installation site: WIPP



- EXO-200 installed at WIPP (Waste Isolation Pilot Plant), in Carlsbad, NM
- 1600 mwe flat overburden (2150 feet, 650 m)
- U.S. DOE salt mine for transuranic waste disposal
- Cleanroom installed on adjustable stands to compensate salt movements.
- Salt “rock” low activity relative to hard-rock mine

$$\Phi_{\mu} \sim 1.5 \times 10^5 \text{ yr}^{-1} \text{ m}^{-2} \text{ sr}^{-1}$$

$$U \sim 0.048 \text{ ppm}$$

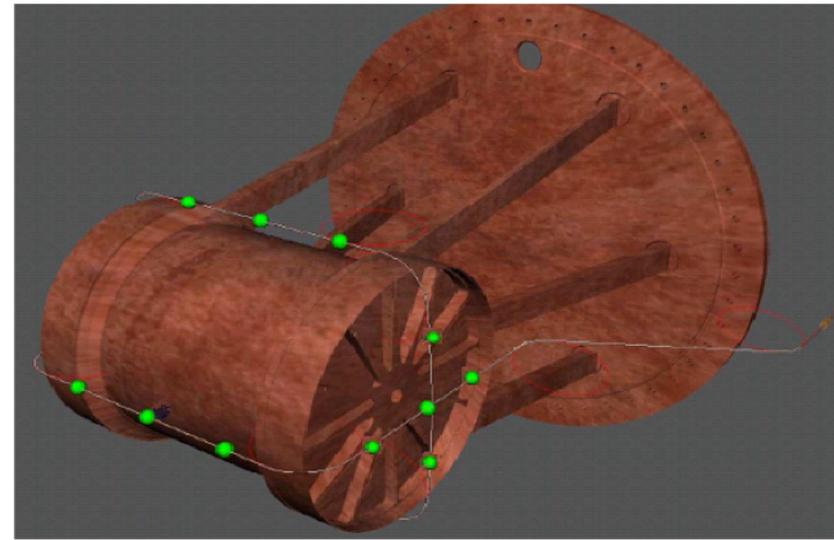
$$Th \sim 0.25 \text{ ppm}$$

$$K \sim 480 \text{ ppm}$$

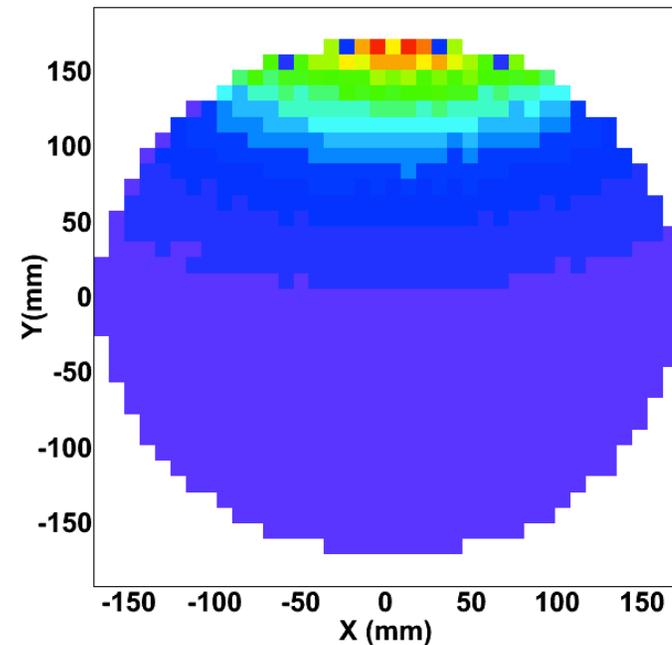
Esch et al., arxiv:astro-ph/0408486 (2004)

Source Calibration

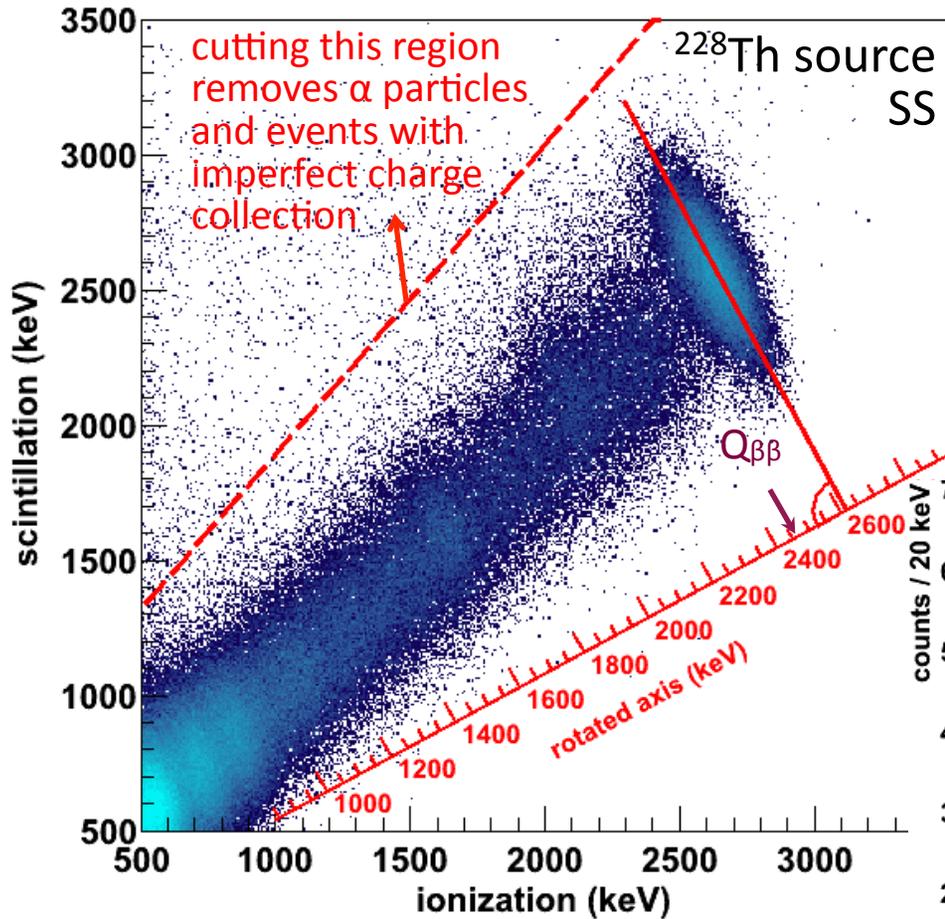
- Calibration Sources are deployed through a guide tube that wraps around the copper vessel.
- ^{137}Cs , ^{60}Co and ^{228}Th sources have been studied.



- Spatial distribution of events clearly shows excess near the source location.



Combining Ionization and Scintillation

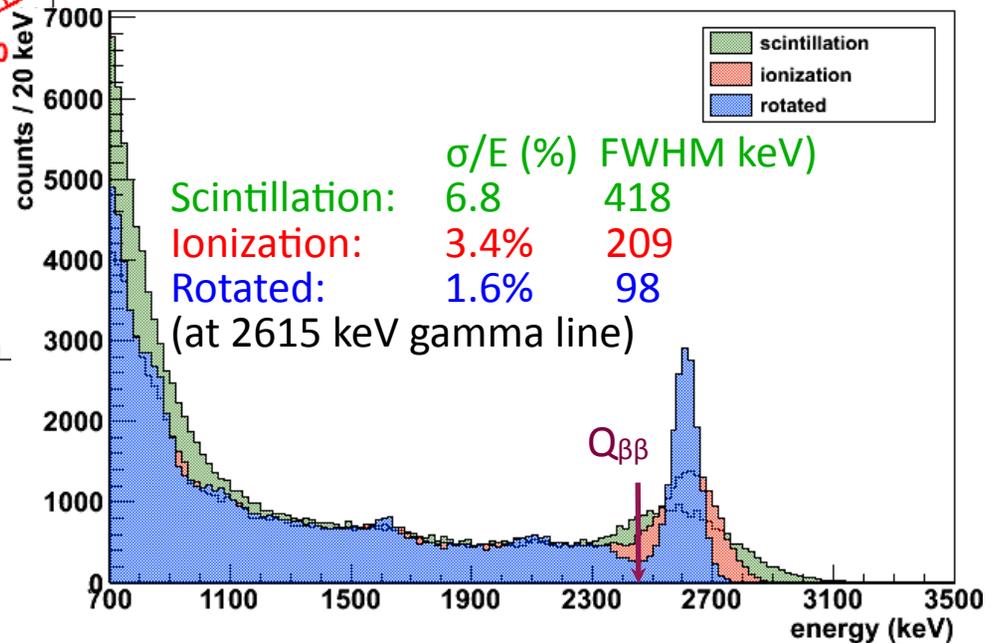


Rotation angle chosen to optimize energy resolution at 2615 keV

Properties of xenon cause increased scintillation to be associated with decreased ionization (and vice-versa)

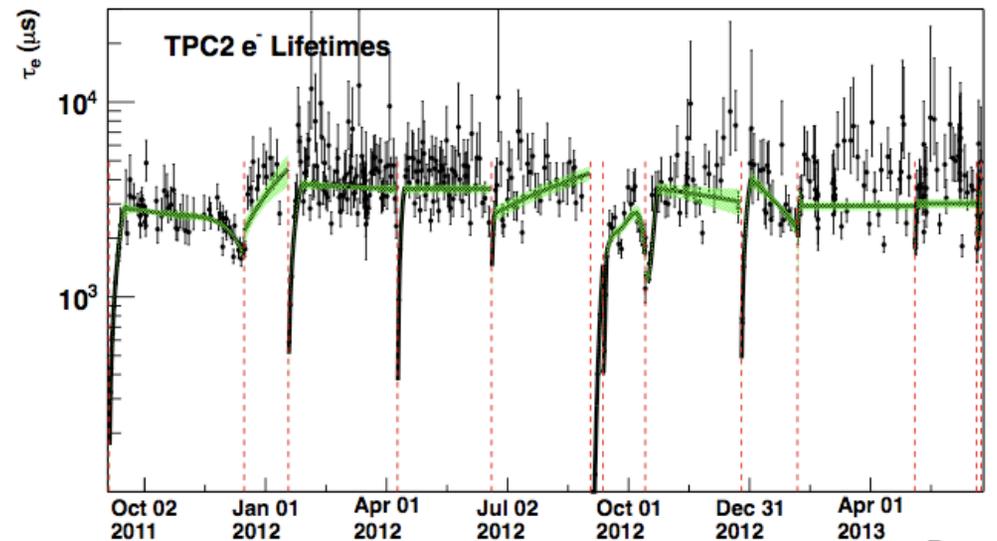
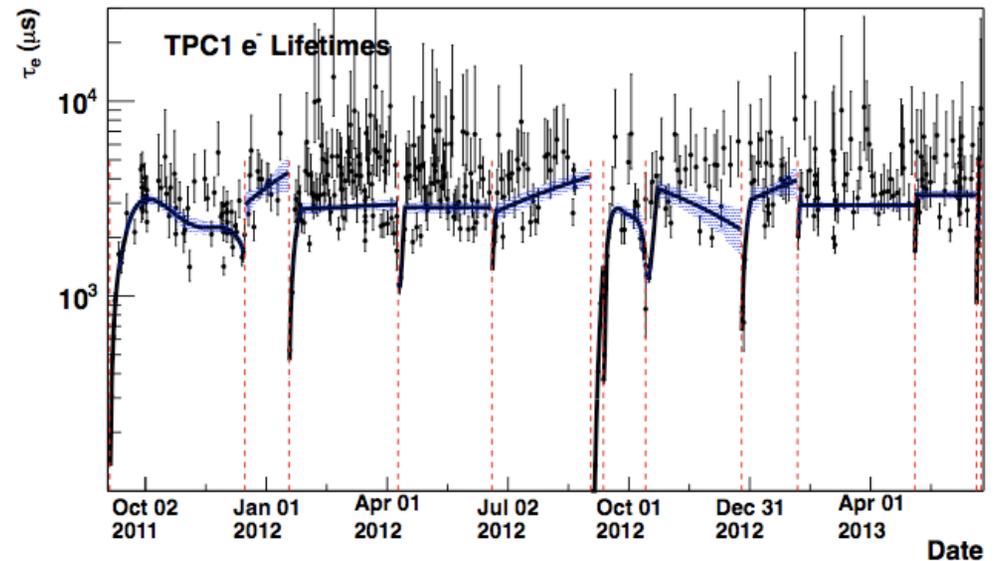
E. Conti et al. Phys. Rev. B 68 (2003) 054201

Use projection onto a rotated axis to determine event energy



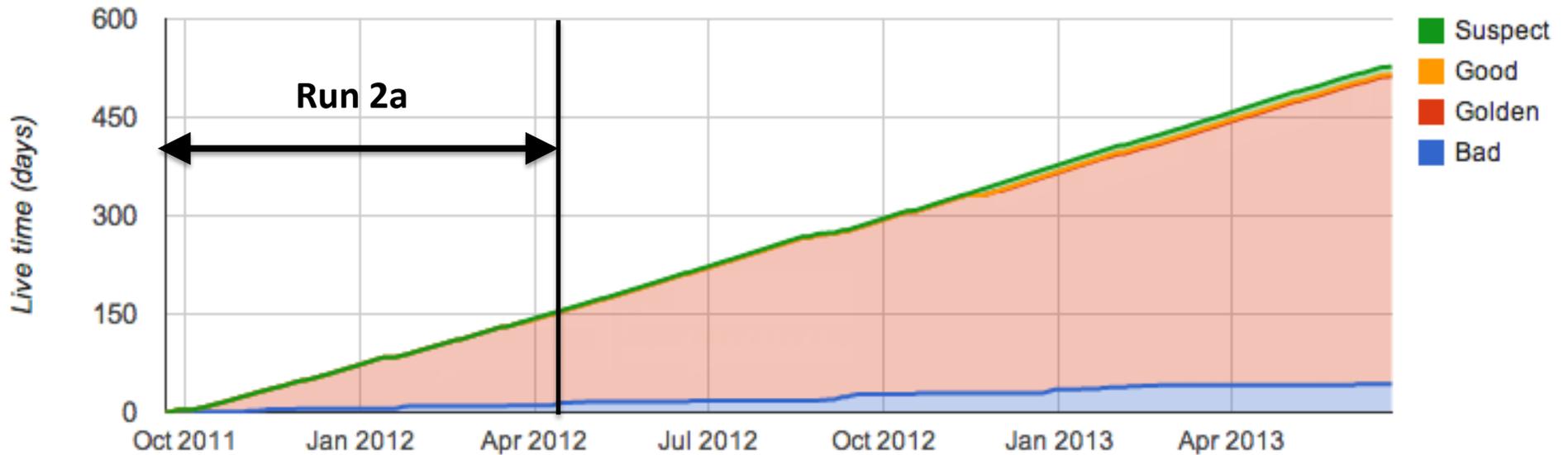
Xenon Purity

- Continuously recirculate Xe through SAES high temperature purifiers using a custom designed magnetic piston pump. [Neilson et al. (2011) arXiv:1104.5041v1].
- Average electron lifetime for $0\nu\beta\beta$ data set was ~ 3 ms with maximum drift time of 110 μs .
- Power outages and other events occasionally require a small fraction of the Xe to be removed from and replaced into the detector, resulting in \sim few day recovery times

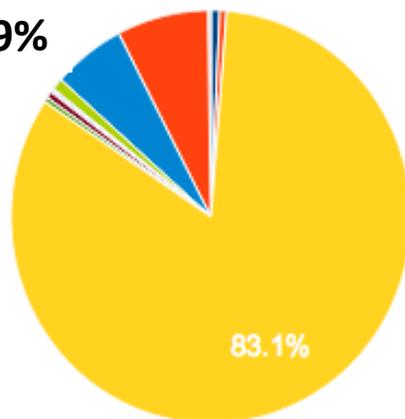


Run 2

Cumulative Livetime vs day for Physics-Data by data quality



All data collection: 92%
Physics Data: 83%
Calibrations/testing: 9%



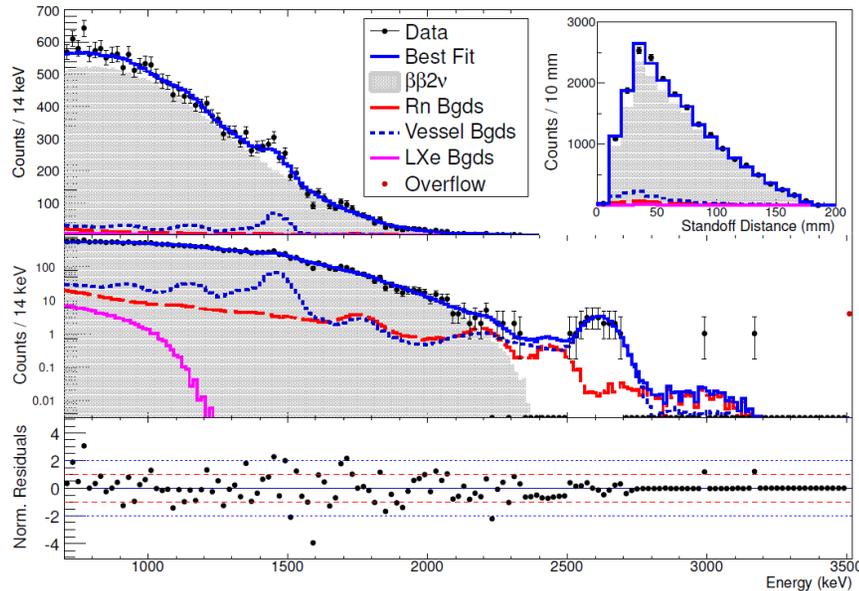
- Charge injection calibration-Int.
- Data-Noise
- Data-Physics
- Data-Source calibration-Co-60:
- Data-Source calibration-Co-60:
- Data-Source calibration-Cs-137...
- Data-Source calibration-Ra-22...
- Data-Source calibration-Th-228...
- Data-Source calibration-Th-228:weak
- No Data Taking
- Other

EXO Run Time Summary

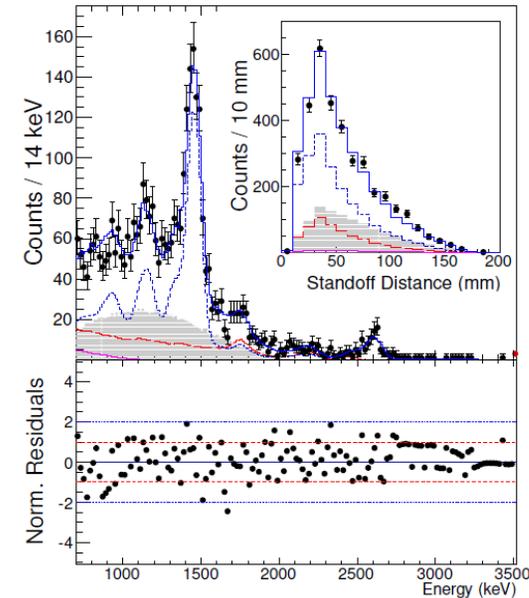
	Run 1	Run 2a	Run 2b	Run 3
Period	May 21, 11 – Jul 9, 11	Sep 22, 11 – Apr 15, 12	Apr 16, 12 – Jun 24, 13	Jun 25, 13 - ...
Live Time	752.7 hr	2,896.6 hr(1) 3,115.48 hr(2)	7,434.09 hr	...
		10,550.4 hr		
Exposure (Xe)	4.4 kg-yr	32.5 kg-yr(1) 28.67 kg-yr(2)		...
		3.6 times exposure compared to Run 2a		
Publ.	PRL 107 (2011) 212501	PRL 109 (2012) 032505(1) arxiv:1306.6106 (2)		...
$T_{1/2}^{2\nu\beta\beta}$ (^{136}Xe) (10^{21} yr)	2.11 ± 0.04 stat ± 0.21 sys	2.23 ± 0.017 stat ± 0.22 sys (1) 2.172 ± 0.017 stat ± 0.06 sys (2)		
$T_{1/2}^{0\nu\beta\beta}$ (^{136}Xe)	N/A	$>1.6 \cdot 10^{25}$ yr (1)		
		Analysis in progress		

Latest Result for $2\nu\beta\beta$

Single-Site Spectrum



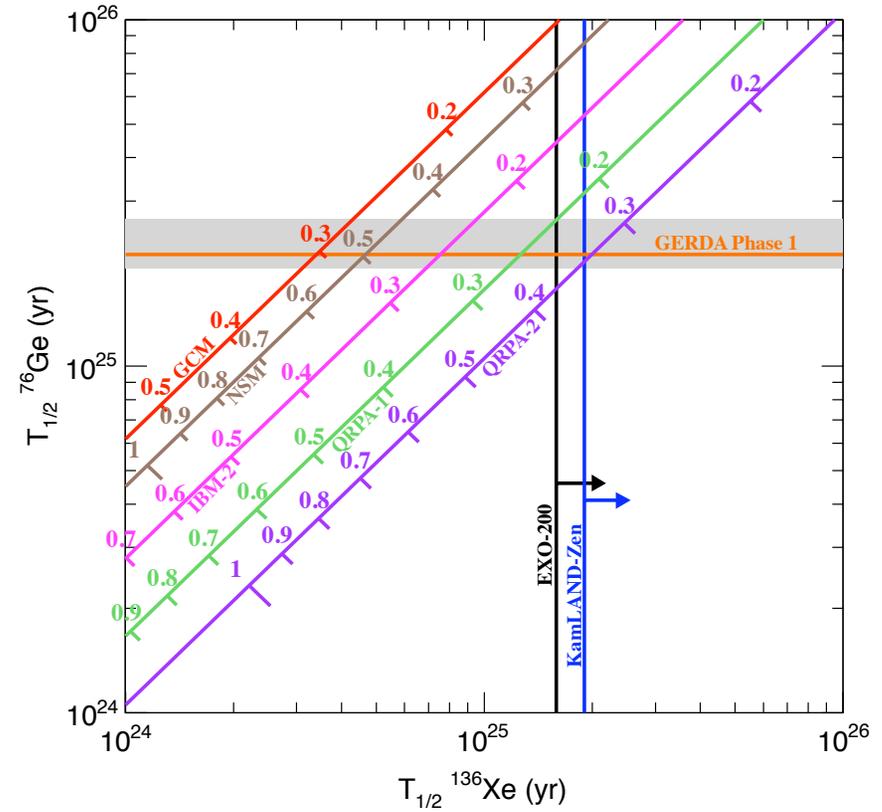
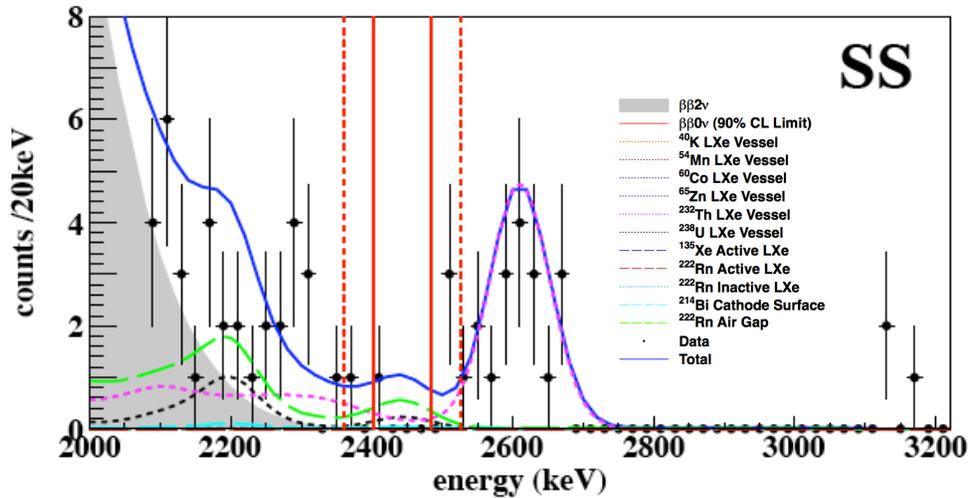
Multi-Site Spectrum



- Single and multi-site spectra analyzed above 700keV.
- Binned log-likelihood fit, in both energy and standoff distance, including $2\nu\beta\beta$ and gamma backgrounds
- Significant improvement made in understanding fiducial volume, resulting in much improved systematic uncertainty (3%)
- Resulting $2\nu\beta\beta$ half-life consistent with previous measurements

$T_{1/2}$ (10^{21}yr)	2.172 ± 0.017 (stat) ± 0.060 (sys)
Exposure ($\text{kg}\cdot\text{yr}$)	23.14
$2\nu\beta\beta$ Detection efficiency	57.88%
$2\nu\beta\beta$ events from fit	18984
Nuclear Matrix Element (MeV^{-1})	0.0217 ± 0.0003

EXO-200 and $0\nu\beta\beta$



- EXO-200 limit¹: $4.6 (1.6) * 10^{25}$ yr at 68% (90%) confidence
- In conflict with discovery claim² in ^{76}Ge for many NME
- New result based on full Run II data set (factor of 3.6 greater exposure than Run IIa) coming soon

¹PRL 109 (2012) 032505

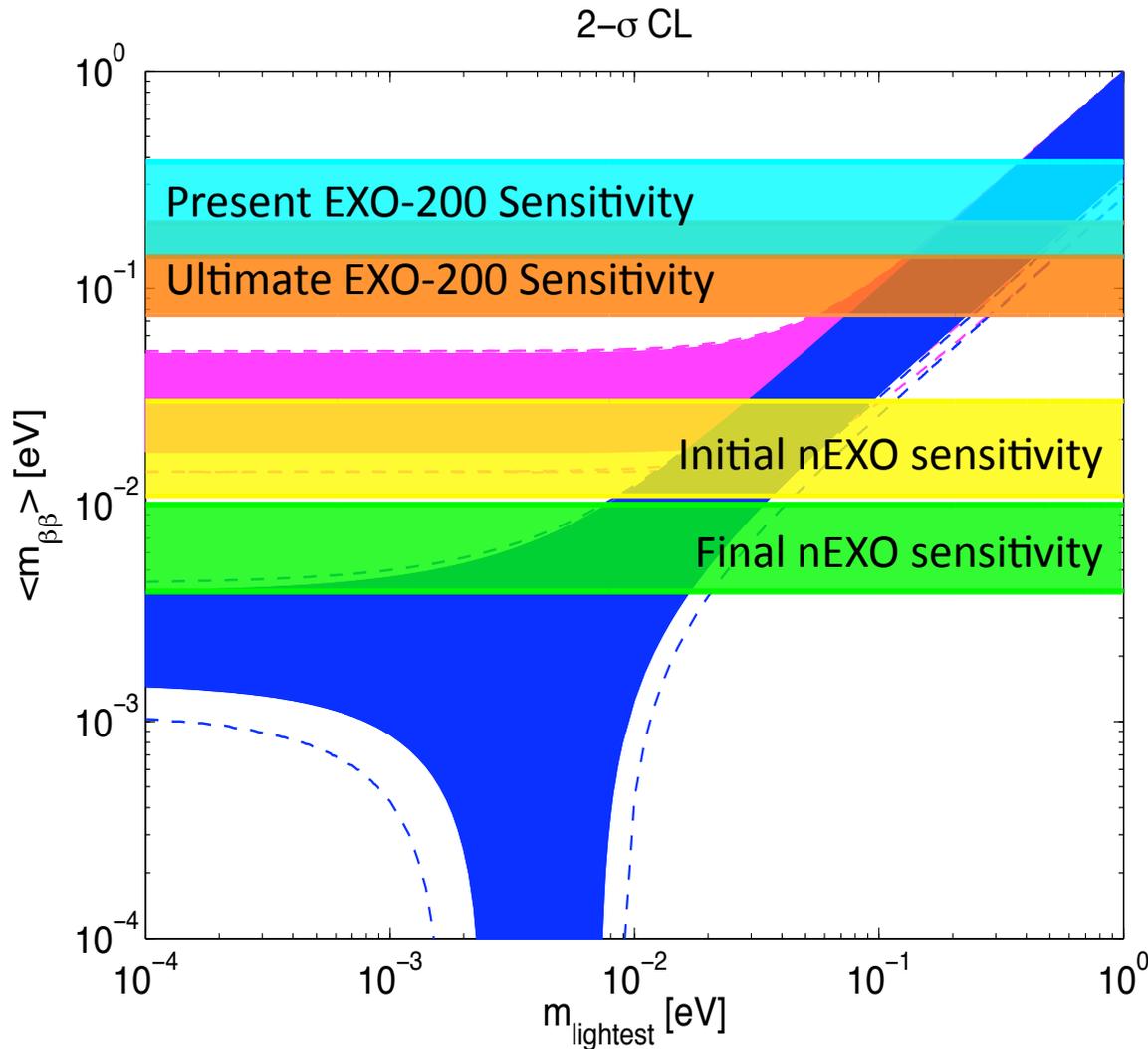
²H.V. Klapdor-Kleingrothaus and I.V. Krivosheina, Mod. Phys. Lett., A21 (2006) 1547.

Deradonator

- “Vacuum-swing adsorption” (VSA) Rn filter for air.
- Air forced through activated charcoal to filter Rn at atmospheric pressure, then regenerated by purge at vacuum
- Dual charcoal columns allow continuous operation at 10-30cfm.
- Shipped out of UMass 9/5/13
- Installation and commissioning soon!



Neutrino Mass Sensitivity



Neutrino parameters: Forero et al. 1205.5254, 95%CL.

The horizontal bands represent the envelopes of the 90% CL limits expected (or obtained for the top-most) assuming various NME calculations and assuming that no signal as detected

The EXO-200 "Present limit" is from PRL 109 (2012) 032505

The EXO-200 "Ultimate" sensitivity: 4 yrs livetime with new analysis & Rn removal.

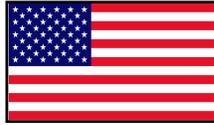
The "Initial nEXO" band refers to a detector directly scaled from EXO-200, including its measured background and 10yr livetime.

The "Final nEXO" band refers to the same detector and no background other than 2ν

Conclusions and Outlook

- EXO's first phase, EXO-200, has already had a major impact
- Data collection ongoing
- Hardware upgrades in progress:
 - Deradonator
 - Electronics upgrade
- More results coming soon!

The EXO Collaboration



University of Alabama, Tuscaloosa AL, USA - D. Auty, T. Didberidze, M. Hughes, A. Piepke

University of Bern, Switzerland - M. Auger, S. Delaquis, D. Franco, G. Giroux, R. Gornea, T. Tolba, J-L. Vuilleumier, M. Weber

California Institute of Technology, Pasadena CA, USA - P. Vogel

Carleton University, Ottawa ON, Canada - V. Basque, M. Dunford, K. Graham, C. Hargrove, R. Killick, T. Koffas, F. Leonard, C. Licciardi, M. Roza, D. Sinclair

Colorado State University, Fort Collins CO, USA - C. Benitez-Medina, C. Chambers, A. Craycraft, W. Fairbank, Jr., N. Kaufhold, T. Walton

Drexel University, Philadelphia PA, USA - M.J. Dolinski, M.J. Jewell, Y.H. Lin, E. Smith

Duke University, Durham NC, USA - P.S. Barbeau

University of Illinois, Urbana-Champaign IL, USA - D. Beck, J. Walton, M. Tarka, L. Yang

IHEP Beijing, People's Republic of China - G. Cao, X. Jiang, Y. Zhao

Indiana University, Bloomington IN, USA - J. Albert, S. Daugherty, T. Johnson, L.J. Kaufman

University of California, Irvine, Irvine CA, USA - M. Moe

ITEP Moscow, Russia - D. Akimov, I. Alexandrov, V. Belov, A. Burenkov, M. Danilov, A. Dolgolenko, A. Karelin, A. Kovalenko, A. Kuchenkov, V. Stekhanov, O. Zeldovich

Laurentian University, Sudbury ON, Canada - B. Cleveland, J. Farine, B. Mong, U. Wichoski

University of Maryland, College Park MD, USA - C. Davis, A. Dobi, C. Hall, S. Slutsky, Y-R. Yen

University of Massachusetts, Amherst MA, USA - T. Daniels, S. Johnston, K. Kumar, M. Lodato, C. Mackeen, K. Malone, A. Pocar, J.D. Wright

University of Seoul, South Korea - D. Leonard

SLAC National Accelerator Laboratory, Menlo Park CA, USA - M. Breidenbach, R. Conley, A. Dragone, K. Fouts, R. Herbst, S. Herrin, A. Johnson, R. MacLellan, K. Nishimura, A. Odian, C.Y. Prescott, P.C. Rowson, J.J. Russell, K. Skarpaas, M. Swift, A. Waite, M. Wittgen

Stanford University, Stanford CA, USA - J. Bonatt, T. Brunner, J. Chaves, J. Davis, R. DeVoe, D. Fudenberg, G. Gratta, S. Kravitz, D. Moore, I. Ostrovskiy, A. Rivas, A. Schubert, D. Tosi, K. Twelker, L. Wen

Technical University of Munich, Garching, Germany - W. Feldmeier, P. Fierlinger, M. Marino

TRIUMF, Vancouver BC, Canada - P.A. Amandruz, D. Bishop, J. Dilling, P. Gumplinger, R. Kruecken, C. Lim, F. Retiere, V. Strickland